Climate Change Trends and Strategies for the George Washington National Forest

Overview

For the George Washington National Forest and much of the southeastern United States, climate variability and weather events such as strong winds and heavy rains from hurricanes, droughts, heat waves, episodes of warm winters, floods, ice storms, and lightning storms have long been part of the natural environment. From a climate perspective, the southeast has some of the warmest temperatures, generally receives more rainfall than any other region, and experiences many extreme climate events (U.S. Global Change Research Program 2001).

These climate variables and associated disturbances have always influenced the makeup and geographical distribution of many ecological communities and landscapes across the South. However, the increasing changes in climate and disturbances projected for the future are expected to lead to substantial alterations in our forests and the services they provide (U.S. Climate Change Science Program, 2008a). The International Panel on Climate Change (IPCC 2007) has identified future impacts of temperature warmings, changes in precipitation, extreme weather events, severe droughts, earlier snowfall, rising sea levels and other changes that could significantly affect forest ecosystems. The complex interaction of all of these factors is shown in Figure X. The Forest Service has identified climate change as ‘one of the greatest challenges to sustainable management of forests and grasslands and to human well-being that we have ever faced, because rates of change will likely exceed many ecosystems’ capabilities to naturally adapt’ (Forest Service Strategic Framework for Responding to Climate Change, 2008).

In light of the importance of this emerging issue, new management strategies are being considered for forest ecosystems across the South. Some of the challenges facing national forests in developing strategies for addressing climate change are the uncertainties about the direction of change, especially at local levels, and how different ecosystems will respond to future natural and human-induced pressures. Forest Service scientists have been studying various aspects of climate change on forests for many years. Yet, our knowledge of how plants and ecosystems respond to the threats of a changing climate and how to react appropriately at local levels where management actions are most effective is still very limited (Solomon 2008). Uncertainties about outcomes will require flexibility, and land management strategies based on current or historical conditions will need to be adjusted or replaced with approaches that support adaptation to changing conditions (USDA Forest Service, October 2008).

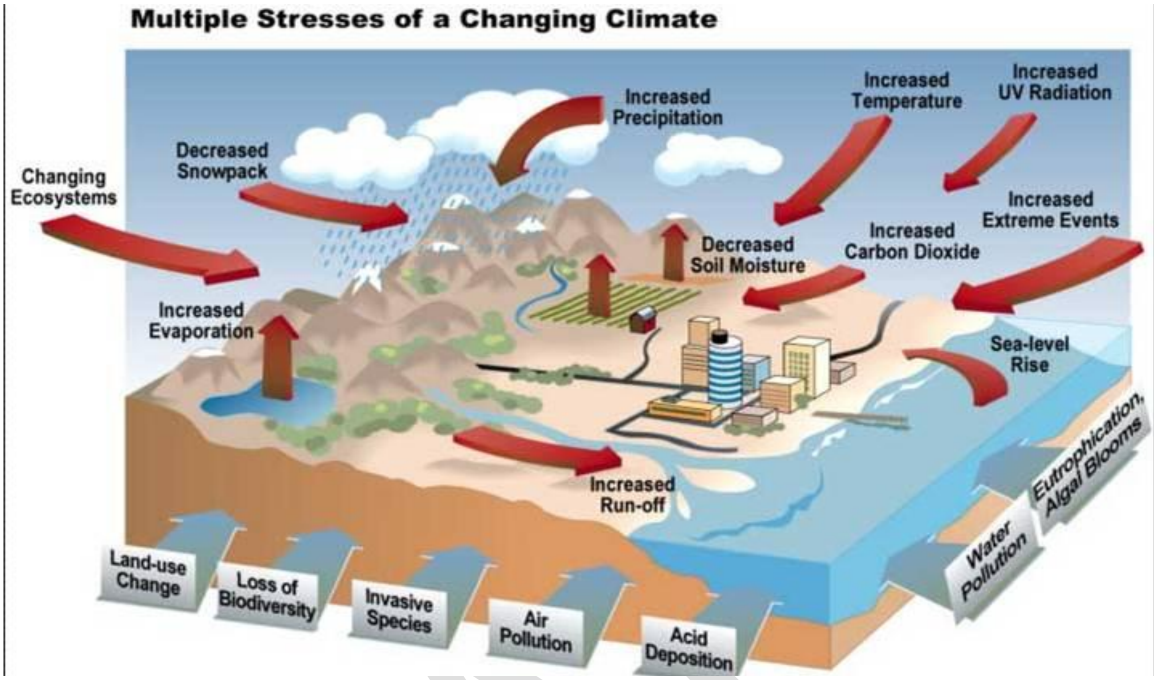

Figure X.

In developing management strategies to deal with a changing climate, it has been recognized that forests can play an important role in both mitigating and adapting to climate change. Mitigation measures focus on strategies such as carbon sequestration by natural systems, ways to increase carbon stored in wood products, ways to provide renewable energy from woody biomass to reduce fossil fuel consumption, and ways to reduce environmental footprints. Adaptation measures address ways to maintain forest health, diversity, productivity, and resilience under uncertain future conditions. Adaptation and mitigation activities must also complement each other and balance with other ecosystem services (USDA Forest Service, October 2008).

Forest Service research activities in the coming years are expected to help both public and private land managers better understand changing conditions and determine appropriate management approaches for both adaptation and mitigation. The global change research approach that will guide Forest Service Research and Development for the next decade will not only address enhanced ecosystem sustainability (adaptation) and increased carbon sequestration (mitigation) but will also provide decision support models for land managers and facilitate scientific collaboration and technology transfer (USDA Forest Service 2008).

At this time, the science of climate change modeling is at the stage of stepping down global models to regional scales (Davis 2007), so a combination of national projections, regional-level climate trends for the southeastern United States, and a recent report prepared for the state of Virginia provides the most reliable context for describing expected climate changes and impacts for the George Washington National Forest. Specifics regarding many mitigation measures, such as the appropriate calculations for carbon offsets and how to consider carbon sequestration rates, are still being developed, so most of our focus at the forest level for now will be on using management options to improve resilience and adaptability of native ecosystems under changing conditions. Then, over the 15-year life of the Plan, as issues are better understood and appropriate measures are identified, climate change strategies can be adjusted through the adaptive management process.

National Climate Change Trends and Expectations

Warming temperatures, altered precipitation patterns, rising sea levels, and increases in the number and intensity of extreme weather events are already causing observed ecological responses across the United States (U.S. Climate Change Science Program, 2008a). Although there are variations by region, overall temperatures across the nation warmed during the 20th century, with 11 of the 12 years from 1995-2006 among the warmest since instrumental record keeping was started in 1850 (U.S. Climate Change Science Program, 2008b; IPCC, 2007). Precipitation patterns and distribution also vary regionally, but the total annual precipitation in the contiguous United States has increased 6.1 percent over the last century, with about half of the increase attributed to increased storm intensity (U.S. Climate Change Science Program, 2008b; Karl and Knight, 1998). Warming temperatures, along with land subsidence, contribute to sea level rise. Relative sea levels have risen 3-4 mm per year in the Mid-Atlantic States and 5-10 mm per year in the Gulf states (U.S. Climate Change Science Program, 2008b; U.S. Environmental Protection Agency, 2007).

Anticipated increases in extreme weather events outside the historic range of natural variability may alter the frequency, intensity, duration, and timing of disturbances such as fire, drought, invasive species, and insect and pathogen outbreaks. Changes in forest composition and growth may also have associated impacts on wildlife habitats, the supply of wood products, specialty markets, and recreational opportunities (U.S. Climate Change Science Program, 2008b; Marques 2008).

Forests provide a wealth of services and products including clean water, clean air, biological habitats, recreation opportunities, carbon storage, timber, specialty commodities, fuel, and aesthetic and cultural values. Scientists have indicated that a changing climate can affect the future biodiversity and alter the function of the forest ecosystems that support these services and products (U.S. Climate Change Science Program, 2008a). Species distributions may shift, some species are likely to decline while others expand, and whole new communities may form. Forest productivity may be reduced in some instances due to a decline in photosynthesis caused by increased ozone, and productivity may be enhanced in other settings where elevated levels of carbon dioxide (CO_2) have a fertilizing effect on overall tree growth.

The overwhelming majority of studies of regional climate effects on terrestrial species reveal consistent responses to warming trends, including poleward and elevational range shifts of flora and fauna. Responses of terrestrial species to warming across the Northern Hemisphere are already well documented by changes in the timing of growth stages (i.e., phenological changes), especially the earlier onset of spring events, migration, and lengthening of the growing season (IPCC 2007).

Mammalian responses to rising temperatures and other climate changes are diverse. Many small mammals are coming out of hibernation and breeding earlier in the year than they did several decades ago, while others are expanding their ranges to higher altitudes. Some show trends toward larger body sizes, probably due to increasing food availability and higher temperatures. On the other hand, reproductive success in polar bears has declined due to melting Arctic sea ice (IPCC 2007).

Birds are an important part of many functioning ecosystems because of their roles in seed dispersal, pollination, and as both predator and prey. Scientists have observed that birds are breeding and laying their eggs earlier and that migratory species have altered their wintering and/or critical stopover habitats. For example, warmer springs have led to earlier nesting for 28 migrating bird species on the east coast of the U.S. (IPCC 2007).

A range shift toward the poles (northward in the Northern Hemisphere) or to higher elevations has occurred among many invertebrates that are considered pests or disease organisms (IPCC 2007).

Habitat ranges for butterflies in North America have shifted northward and in elevation as temperatures increased. In some cases, such as the Edith's Checkerspot Butterfly, local populations have become extinct in the southern portion of their range (IPCC 2007).

Fishing is highly valued in the U.S. as both a commercial enterprise and as a recreational sport. Fish populations and other aquatic resources are likely to be affected by warmer water temperatures, changes in seasonal flow regimes, total flows, lake levels, and water quality. These changes will affect the health of aquatic ecosystems, with impacts on productivity, species diversity, and species distribution (IPCC 2007).

Stream habitats are projected to decline across the U.S. by 47 percent for coldwater, 50 percent for cool-water, and 14 percent for warm-water species. In the southern Great Plains, summer water temperatures already approach the limits for survival of many native stream fish (IPCC, 2002). An 8°F increase in average annual air temperature is projected to eliminate more than 50 percent of the habitat of brook trout in the southern Appalachian Mountains. The Northern pike, which spawn in flooded meadows in early spring and whose young remain in the meadows for about 20 days after hatching, would be especially affected by low spring water levels. Higher winter temperatures have been observed to decrease the survival rate of the eggs of yellow perch (a coldwater species). On the other hand, one study found that higher winter temperatures (by 2ºC) were beneficial for rainbow trout but the same temperature increase in summer caused negative effects (IPCC 2007).

The ability of reptiles and amphibians to adapt to changes in climate depends in part on their ability to move to more suitable habitat. A European study found that most reptile and amphibian species could expand their ranges in a warmer climate if dispersal were unlimited, but if they were unable to disperse then the ranges of nearly all species (more than 97 percent) would become smaller (IPCC 2007).

Southern Region Climate Change Trends and Expectations

Over the past decade, a number of models have been developed to simulate climatic effects anticipated in the future. These scenarios are based on historical data, trends, and analysis of different plausible assumptions. While climate model simulations are continuing to be developed and refined, climate projections typically do not yet accurately address expected conditions below the regional scale in the United States. In the report by the United States Global Change Research Program on Climate Change Impacts on the United States (2001), the two principal models that were found to best simulate future climate change conditions for the various regions across the country were the Hadley Centre model (developed in the United Kingdom) and the Canadian Climate Centre model. Unless otherwise noted, the following discussions of climate change expectations for the southeastern United States are based on findings from the 2001 U.S. Global Change Research Program report and more recent projections in the U.S. Climate Change Science Program Reports (SAP 4.3, May 2008a; SAP 4.4, June 2008b).

For some aspects of climate change, virtually all models agree on the types of changes to be expected for the southern region:

The climate is going to get warmer, especially warmer minimum winter temperatures. Both the Hadley and Canadian models show increased warming in the southeast but at different rates (see inset on Future Climate Scenarios for the southeast). Overall regional temperature changes are projected to be equivalent to shifting the climate of the Southern U.S. to the central U.S. and the central U.S. climate to the northern U.S.

The heat index, which is a measure of comfort based on temperature and humidity, is going to rise. The principal climate model simulations agree that the heat index will increase more in the

> Future Climate Scenarios for the Southeast
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> Warmer temperatures:
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> Maximum summer temperature increase:
>
> Hadley model = 2.3° F (2030)
>
> Canadian = 5° F (2030), 12° F (2100)
>
> Mean annual temperature increase:
>
> Hadley = 1.8° F (2030), 4.1° F (2100)
>
> Canadian = 3°F (2030); 10° F (2100)
>
> Higher summer heat index (average increase):
>
> Hadley model = 8-15° F (2100)
>
> Canadian model = 15° F (2100)
>
> Moisture changes:
>
> Intensified El Nino & La Nina phases as CO_2 increases.
>
> Hadley = 20% increased moisture by 2090
>
> Canadian = decreased moisture; droughts

southeast than in other regions. By 2100, the heat index under the Hadley model is projected to increase by as much as 8-10°F and by over 15°F in the Canadian model. The Northeast may feel like the southeast does today, the southeast is likely to feel more like today's south Texas coast, and the south Texas coast is likely to feel more like the hottest parts of Central America.

Threats to coastal areas will increase, including rising sea levels, beach erosion, subsidence, salt water intrusion, shoreline loss, and impacts to urban development.

Precipitation is more likely to come in heavy, extreme events.

For other aspects, models tend to differ on expectations. The southeast is the only region where climate models are simulating large and opposite variations in precipitation patterns over the next 100 years. The Canadian model projects more extensive and frequent droughts in the southeast, starting with little change in precipitation until 2030 followed by much drier conditions over the next 70 years. The Hadley model, in contrast, suggests there will be a slight decrease in precipitation over the region during the next 30 years followed by increased precipitation. There is also uncertainty over the extent of effects of El Nino and La Nina cycles. El Nino events typically result in cooler, wetter winters in the southeast and fewer Atlantic tropical storms, while La Nina events tend to have the opposite effects with warmer, drier winters and more hurricanes.

Unexpected interactions among multiple disturbances happening at the same time add to the level of uncertainty. For example, tree growth is generally projected to be stimulated by increases in CO_2, but limits on availability of water and soil nutrients during droughts often weaken tree health leading to insect infestations or disease, which in turn promotes future fires by increasing fuel loads and further weakening tree health (Marques 2008).

Based on current projections, the following discussion highlights some of the potential impacts of a changing climate on forests in the southeastern United States and on the George Washington National Forest.

<u>Forest productivity</u> – In general, biological productivity of southeastern forests will likely be enhanced by increased levels of CO_2, as long as there is no decline in precipitation and as long as any increases in moisture stress due to higher air temperatures are low enough to be offset by CO_2 benefits. Hardwoods are more likely to benefit from increased CO_2 and modest temperature increases than pines, since pines have greater water demands than hardwoods on a year-round basis. Without management adaptations, simulations using the Hadley model show pine forest productivity will likely increase 11 percent by 2040 and then exhibit a declining trend to an 8 percent increase by 2100 compared to 1990 productivity estimates. Hardwood productivity will likely continue to rise, with projections of a 22 percent increase by 2040 and 25 percent by 2100. This shift in productivity could have significant effects in the South. Forest productivity increases may be offset, however, by escalating damage from forest pests and more extreme weather disturbances.

<u>Forest pests</u> – The potential for a changing climate to increase the distribution of forest pests and diseases is a concern, particularly for pests that already cause widespread damage such as Southern pine beetles. Higher winter temperatures are expected to increase over-wintering beetle survival rates, and higher annual temperatures will produce more generations each year leading to increased beetle infestations. Other factors, however, complicate projections of future infestation levels. Field research has demonstrated that moderate drought stress increases pine resin production thus reducing colonization success, while severe drought stress reduces resin production and increases pine susceptibility to beetle infestation. Insufficient evidence currently exists to predict which of these factors will control future beetle populations and impacts (McNulty et al. 1998).

<u>Fires</u> – Fire frequency, size, intensity, and seasonality are directly influenced by weather and climate conditions. Nationwide projections show seasonal fire severity is likely to increase by 10 percent over the next century, with possibly larger increases in the southeast. At least two ecosystem models run under the Canadian climate change scenario suggest a 25-50 percent increase in fires, and a shift of some southeastern pine forests to pine savannas and grasslands due to moisture stress. Under a hotter, drier climate, an aggressive fire management strategy could prove critical to maintaining regional vegetation patterns.

<u>Shifts in major vegetation types for the Southeast</u> – The broad variety of ecosystem types found across the southeast ranges from coastal marshes to mountaintop spruce-fir forests. Although the South is one of the fastest growing population regions in the country, forests are still common in many parts of the southeast, and forestland averages approximately 30 percent of each state. Potential changes in vegetation distribution due to climate change vary with different model scenarios. Under the Hadley model, forests remain the dominant natural vegetation in the southeast, but the mix of forest types changes. Under the Canadian model, savannas and grasslands expand and replace parts of the southeastern pine forests along the Coastal Plain due to increased moisture stress. In this scenario, the current southeastern forest moves into the north-central part of the United States. Both drought and increased fire disturbance play an important role in the potential forest breakup.

<u>Weather-related stresses on human populations</u> – Low-lying Gulf and Atlantic coastal areas are particularly vulnerable to flooding. With floods already the leading cause of death from natural disasters in the southeast, increased flooding from more active El Nino/La Nina cycles could have greater adverse impacts. Even if storms do not increase in frequency or intensity, sea level rise alone will increase storm surge flooding in virtually all southeastern coastal areas. Another concern is the prolonged effect of elevated summertime heat events, which coupled with drought conditions, not only causes elevated heat stress to humans but also increases smog levels.

<u>Increased forest disturbances</u> – Increases in extreme events and changes in disturbance patterns may have more significant impacts, at least in the near future,

than long-term changes in temperature or precipitation. Natural disturbances that may be associated with climate change include hurricanes, tornadoes, storms, droughts, floods, fires, insects, diseases, and non-native invasive species. Although disturbances are a natural and vital part of southern ecosystems, it is the change in frequency, intensity, duration, and timing exceeding the natural range of variation that is a concern (Marques 2008). Multiple disturbances interact and further exacerbate damages. Hurricanes can cause severe disturbance that not only results in direct loss of biological communities and habitat, but the widespread damages can also shift successional direction leading to higher rates of species change and faster biomass and nutrient turnover. Invasive species and insect pests often have high reproductive rates, good dispersal abilities, and rapid growth rates enabling them to thrive in disturbed environments.

Water stresses – The difficulty in predicting whether precipitation will increase or decrease in the southeast over the next 30-100 years extends to uncertainties over future water quantity and quality conditions. Current water quality stresses across the southern region of the country are primarily associated with intensive agricultural practices, urban development, and coastal processes such as saltwater intrusion. Although water quality problems are generally not critical under current conditions, stresses are expected to be more frequent under extreme conditions, particularly in low stream flow situations associated with droughts. Under the Hadley model, stream flow in the southeast has been projected to decline as much as 10 percent during the early summer months over the next 30 years. The Chattahoochee and Tombigbee River basins are projected to have decreased water availability over the next 50 years, and as stream flow and soil moisture decrease, agricultural fertilizer applications and irrigation demands tend to increase creating further stress and conflicts over competing uses. Parts of the southeast that depend more on ground water are particularly vulnerable to depletion of aquifers, which can take centuries to recharge after chronic drought conditions (Hoyle 2008).

Outdoor recreation – Outdoor recreation opportunities are likely to be impacted by climate change but would vary by location and activity. Higher summer temperatures could extend summer activities such as swimming and boating but may also reduce other outdoor activities such as hiking and trails use in hot, humid sections of the South. Warmer waters would increase fish production and fishing opportunities for some species but decrease fishing for other cold water species. Summer recreation activities are likely to expand in cooler mountainous areas as temperatures warm along the coastal plain and lowland elevations. Skiing opportunities are likely to be reduced in the South, and some marginal ski areas may close due to fewer cold days and snow events.

Local Level Climate Change Trends and Expectations

In December 2008, the Governor's Commission on Climate Change released a "Final Report: A Climate Change Action Plan" for the state of Virginia. The report included expected impacts of climate change on Virginia's natural resources, the health of its citizens, and the economy which included the industries of forestry and tourism. It also identified what Virginians can do to prepare for the likely consequences of climate change as well as an estimation of the amount of, and contributors to, the state's greenhouse gas emissions through 2025. The Governor's Executive Order 59 (2007) set a greenhouse gas emission target of 30% below the business-as-usual projection of emissions by 2025.

The Governor's Commission on Climate Change used the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report as the primary reference point on the science of climate change, and also included testimony of a variety of experts. Estimates provided in the recent Chesapeake Bay Program Scientific and Technical Advisory Committee (STAC) report, "Climate Change and the Chesapeake Bay: State-of-the-Science Review and Recommendations" (Pyke et al. 2008) were also incorporated because of its regionally-specific nature. The findings of the expected impacts of climate change for Virginia from the Commission's report, as they relate to national forest management in Virginia include the following. These impacts could be further compounded by Virginia's growing human population. As of July 2009, the Virginia Employment Commission estimates that, between 2010 and 2030, Virginia's human population will increase by almost 23 percent (http://www.vec.virginia.gov/vecportal/lbrmkt/plugins/lmiapp.cfm/popproj#).

- Virginia should prepare for a minimum of a 3.6ºF increase in air and water temperatures but these temperatures could increase as high as 10.8ºF by 2100. Changes in precipitation and weather patterns are more difficult to estimate, although there has been scientific consensus that most of Virginia will experience a slight (0-10%) increase in precipitation and an increase in coastal storm intensity (IPCC, 2008; Pyke et al., 2008).
- There will likely be a projected sea level rise for coastal Virginia of 2.3–5.2 feet by 2100. Oxygen levels in the Chesapeake Bay are expected to decrease due to increasing temperatures and increasing storm runoff. Acidification of the Bay and Atlantic Ocean also is a concern as waters absorb more carbon dioxide (CO_2). Though the George Washington National Forest lies along the western mountains of Virginia, all of the forest is in the headwaters of the Chesapeake Bay watershed.
- At varying rates, vegetation ranges will move from current locations to higher altitudes and latitudes, such that suitable habitat for some species will decline, other species will become extirpated, and other species will become extinct. Virginia's freshwater streams and high elevation areas currently offer essential habitat to many species that require cooler conditions. As temperatures increase and precipitation patterns change, these habitats will no longer support the same suite of species they do today.

- Threats already faced by Virginia's ecosystems, such as invasive species, pathogens and pollution will become exacerbated. Many new exotic or invasive species may move into Virginia and existing pest species may flourish and cause more widespread damage than they are now.
- There is a lack of research and specific information on the impacts of climate change on Virginia's forestry industries, and commercial and sport fishing industries.
- Virginia's forestlands sequester approximately 23 million metric tons of CO_2 per year but an average of 27,000 acres of forestland is lost annually to development. The George Washington National Forest encompasses about 1 million acres (or seven percent) of the forestlands in the state. The Jefferson encompasses another five percent, making both forests the largest land manager in the state. The GW also includes about 105,000 acres in West Virginia.
- Extreme weather events could lead to compromised water and food supplies for people. Unstable weather patterns could also cause periods of drought that threaten municipal water supplies.
- Climate change is expected to increase the incidence of human diseases associated with air pollutants and aeroallergens that exacerbate other respiratory and cardiovascular conditions.
- The three largest sources of greenhouse gas emissions in Virginia are electricity generation, transportation and non-utility uses of fuel in industrial, commercial and residential facilities. Demands for electricity, transportation and fuel would likely increase as population increases.
- The Virginia Department of Mines, Minerals and Energy (DMME) projects that natural gas consumption will grow 3.6 percent from 2007 through 2016 under a business-as-usual scenario. Natural gas increasingly is being used for electric generation because it is the cleanest of the fossil fuels, which may cause an even greater increase in demand for natural gas supply.
- While most of the Commission report's recommendations focused on greenhouse gas emission reduction, the following recommendations could be incorporated into the plan components or management approach for the George Washington National Forest:
- Virginia should establish a greenhouse gas monitoring and reporting system.
- Conserve existing natural carbon sinks and increase the capacity of those carbon sinks to decrease net greenhouse gas emissions.
- Incorporate the planning documents of the Virginia Department of Conservation and Recreation (Natural Heritage Plan) and the Virginia Department of Game and Inland Fisheries (Wildlife Action Plan) that

identify important habitat types, specific habitat sites, areas important for maintaining biodiversity, and conservation actions needed to conserve all of Virginia's wildlife and native habitats.

- Virginia state agencies and universities should work with federal partners to develop regional adaptive resource management plans that incorporate climate change impacts. Priorities should be given to maintaining resiliency and diversity and connectivity in natural systems.

Key Climate Change Factors and Effects for the George Washington National Forest

Based on current projections, the primary regional-level and state-level predicted effects of climate change that would impact the Forest include: (1) warmer temperatures; (2) extreme weather events; and (3) increased outbreaks of insects, disease, and nonnative invasive species.

Increased variation in temperature and moisture can cause stress and increase the susceptibility of forest ecosystems to invasions by insects, diseases, and non-native species. New environmental conditions can lead to a different mix of species and tend to be favorable to plants and animals that can adapt their biological functions or are aggressive in colonizing new territories (Whitlock 2008). However, changes in adaptability may be too slow given the predicted rate of change. Species that are already broadly adapted may become more prevalent, and species with narrow adaptability may become less prevalent. Disturbance factors that create more vulnerability in native ecosystems or require extensive controls to maintain the status quo are likely to affect desired conditions for healthy and diverse forests.

Desired conditions for healthy forests include resilience to dramatic change caused by abiotic and biotic stressors and mortality agents (particularly the southern pine beetle, gypsy moth, hemlock woolly adelgid and emerald ash borer on the GWNF) and a balanced supply of essential resources (light, moisture, nutrients, growing space). For the GWNF, gypsy moth epidemics have caused the greatest insect damage to date. The hemlock woolly adelgid affects only one species of trees but the loss of hemlocks in the riparian corridors has had widespread impacts, especially when coupled with the continuing effects of acid deposition. The forest has experienced several localized outbreaks of southern pine beetle. Emerald ash borer has been found in the northern parts of Virginia so far.

One of the natural disturbances that are an integral part of the forest is fire. Many of the native ecosystems that make up the George Washington National Forest, such as the pine and pine-oak forests, are adapted to or dependent on some level of periodic fire. Fire frequency, size, intensity, seasonality, and severity are highly dependent on weather and climate. As noted earlier, model results predict that seasonal severity of fire hazard is likely to increase by 10 percent over much of the United States during the 21st century, with possibly larger increases in the southeast (U.S. Global Climate

Change Program 2001). The warmer Canadian model scenario which anticipates increased drought stress, projects a 30 percent increase in fire severity for the southeast. If extreme events such as hurricanes further increase forest fuel levels with widespread downed trees, there is a potential for larger, more catastrophic fires that could impact many of the desired conditions for the George Washington National Forest.

Warmer temperatures may lead to increased visitation to the George Washington National Forest for cooler, mountainous temperatures or for water-based recreational opportunities. A longer warm season could lengthen the recreation season on the Forest. Hunting and fishing seasons may be longer. Maintenance needs for roads and infrastructure could be greater. Demand for more highly developed recreation facilities (electricity) may increase. These effects would also be exacerbated by increasing population levels.

Scenery is one of the most valued quality of life benefits for life in the mountains of Virginia and West Virginia. Climatic effects on air quality could alter the visibility of landscapes.

Increases in extreme weather events have the potential for the occurrence of landslides and debris flows. The potential effects may be more important as the population and infrastructure continue to increase in areas adjacent to the National Forest.

The expected effects of climate change to aquatic systems can be described by predicted changes to physical processes and the potential impacts to physical and biological systems (Bakke 2008). For the area covered by the George Washington National Forest, these include:

1) Increased storm intensity, including intensity of precipitation, would increase surface erosion, increase the magnitude and variability of peak flows, and increase sediment load to rivers;
2) Changes to total annual precipitation amount and seasonal distribution, could cause an increase in winter precipitation, a decrease in summer precipitation, an increase in average runoff in winter and spring months, and decreased summer base flows;
3) Increased flood risk and resultant channel instability, would increase channel migration and associated streambank erosion, and shift 100 year floodplain boundaries;
4) Increase in average water temperature would shrink usable habitat for cold water species and shift habitat types. Warmer water temperatures would mean lower dissolved oxygen, and there would be a disproportionate importance of groundwater-fed systems to cold water species. A recent study (Flebbe et al. 2006) projects that rising temperature changes from climate change (and the loss of hemlock along streams) will shrink native trout

habitat. Using the Hadley Centre model (2.5°C air temperature increase) and the Canadian Centre model (5.5°C air temperature increase), Flebbe found that between 53 and 97 percent of wild trout habitat could be lost as streams become warmer by the year 2100.

5) Increased evapotranspiration and loss of soil moisture would reduce baseflow in rivers, reduce groundwater recharge, and result in loss of wetland area, including conversion of perennial to seasonal wetlands;
6) Changes in vegetation cover and species composition could change long-term wood dynamics, alter erosion rates, and change riparian cover and energy inputs (Bakke 2008).

Aquatic systems may not only be affected by changes in the above physical processes in response to climate change, but also by the following changes in human management of land and natural resources:

- Increased demand for structural streambank protection
- Increased groundwater withdrawals in response to declining surface water resources
- Increased demand for irrigation water
- Increased demand for surface water storage and flood control reservoirs
- Increased renewable energy development, impacting new areas on the landscape (Bakke 2008).

Even with more stringent air quality controls, acid deposition is expected to continue to impact the Forest. Research is currently evaluating the link between soil acidification and the nesting success of high elevational birds since female songbirds need large amounts of calcium (from snail shells) to produce eggs (SRS Compass, Issue 10). Much of the high elevational habitat for songbirds is found on the GWNF and is one of the more vulnerable habitats to acid deposition on the forest.

In the Aquatic Sustainability Analysis report, watersheds on the Forest were categorized for their sensitivity to acidification. About 67% of the perennial streams on the Forest were found to be within highly sensitive watersheds, based on underlying geology and deposition rates. The smallest streams at the highest elevations, with non-carbonate bedrock were the most susceptible to acidification.

In summary, our more vulnerable ecosystems include:

- Spruce forests (sensitive to acid deposition, occupy higher elevations, habitat for sensitive species)
- Trout streams (sensitive to stream temperatures)
- Pine ecological systems (declining now, susceptible to southern pine beetle, fire-dependent)
- Higher elevation habitats

- Acid sensitive streams
- Acid sensitive soils

Potential Climate Change Management Strategies

We have always experienced droughts, flooding, extreme weather events, catastrophic fire, insects and disease, and to a more gradual degree, movement in the ranges of floral and fauna species. Many of our current management strategies already strive to maintain or enhance the health and resiliency of various forest resources to better withstand environmental stresses and human-induced pressures. However, the effects of an accelerated rate of change and an increase in the intensity of these impacts on forest resources and ecosystems are still unpredictable. Climate change effects are multiple, varied, and interact with many other stressors/variables. Therefore, an adaptive management approach that monitors forest resource conditions, and monitors the current state of scientific knowledge related to responses to climate change, is needed that will allow us to proactively adjust current strategies or adopt new strategies as needed.

The strategies for the George Washington National Forest focus on both adaptation (ways to maintain forest health, diversity, productivity, and resilience under uncertain future conditions) and mitigation (such as carbon sequestration by natural systems, ways to provide renewable energy to reduce fossil fuel consumption, and ways to reduce environmental footprints). These strategies focus on: 1) reducing vulnerability by maintaining and restoring resilient native ecosystems; 2) providing watershed health; 3) providing carbon sinks for sequestration; 4) reducing existing stresses; 5) responding to demands for cleaner energy including renewable or alternative energy; and 6) providing sustainable operations and partnerships across landscapes and ownerships.

Reduce Vulnerability by Maintaining and Restoring Resilient Native Ecosystems

The primary focus of the revised Forest Plan should be the emphasis on ecosystem resiliency that will support ecological systems diversity and species viability now and in the future. Maintaining and restoring healthy ecosystems that can tolerate, or appropriately adapt to, changes in environmental and social conditions are our best strategy for preparing for potential changes from unusual climate variations. Management strategies to maintain and restore resilient native ecosystems are:

- Identify desired conditions and objectives to maintain the resilience and function of nine identified ecological systems and determine the desired disturbance regimes, including fire, for those ecosystems (e.g. the spruce habitat at Laurel Fork). Priorities for management activities could be identified for our more vulnerable ecosystems.

- Incorporate the use of unplanned fire ignitions as a tool for achieving resource management desired conditions.
- Plant blight-resistant American chestnut seedlings.
- Maintain or restore ecological conditions that are rare on the forest, such as the high elevation early successional habitat, open woodlands, old fields, rare communities, and special biological areas.
- Identify species that may need to move or migrate for populations to remain viable. Determine the types of connectivity and habitat features required to facilitate the movement of those species.
- Identify land acquisition and exchange priorities that include high elevation habitats or connectivity corridors.
- Consider shortleaf pine restoration opportunities.
- Develop limits of acceptable change or capacity studies for high use recreation facilities and trails. Monitor for resource impacts.

Watershed Health

Projected climate changes to the hydrologic cycle through warmer water temperatures, more intense storms, and greater inter-annual variability in precipitation, indicate the importance of maintaining and protecting healthy watersheds. Bakke (2008) describes three key components relating climate change processes to management and conservation of aquatic resources; resilient habitat, refugia, and restoration.

Resiliency refers to the ability of a system to return to its original condition after being disturbed. In ecology, resiliency carries the additional meaning of how much disturbance a system can “absorb” without crossing a threshold and entering an entirely different state of equilibrium. This requires that certain key habitat characteristics or processes will change little; with respect to stream aquatic habitat, these key elements are temperature and disturbance regime. Rivers and streams most resilient to temperature change include those dominated by groundwater input. Aspect, riparian shading, and valley shape also play a role in thermoregulation. A resilient disturbance regime would be one where peak flows and available sediment sources do not become altered. Likewise, streams most resilient to changes in disturbance regime would include those with flow dominated by groundwater. Resiliency can only function if the landscape offers a redundancy of habitat opportunities; there must be enough habitat and connectivity so that a disturbance to one area allows populations to recover and recolonize from another area.

Refugia are places in the landscape where organism can go to escape extreme conditions, be it short term or long term. Protecting these areas, and maintaining or improving connectivity will be increasingly important.

Restoration should include activities which reestablish the structures and function of the stream ecosystem in a manner that the ecosystem will become self-maintaining.

High priority actions would be protection of good habitat, improving connectivity and access to existing habitat. If active restoration, such as enhancement of instream habitat with large wood, is to be performed in potentially unstable settings, it will be important to design these projects with the appropriate level of redundancy to accommodate greater rates of channel migration and flood magnitudes. Passive restoration techniques, such as establishment of wider riparian buffers, may be a more sustainable alternative in light of increased geomorphic instability.

Specific management strategies the George Washington National Forest can adopt to address the management and conservation of aquatic resources in light of predicted effects from climate change are:

- Protect and restore beaver meadows, wetlands, and floodplains to improve natural storage, reduce flood hazards, and prolong seasonal flows. Beaver ponds and wetlands recharge groundwater, raise the water table, retain sediment and organic matter, store water during floods and release it slowly, mitigate low flows and drought, reduce carbon turnover rate, raise pH and ANC, while reducing SO^2, Al, and NO^3 .
- Protect and restore riparian forests to moderate changes in stream temperature, maintain stream bank stability, and provide instream habitat.
- Remove migration barriers and re-establish habitat connectivity so that species can more to more suitable habitat, or move to or from refugia.
- Reduce flood and wildfire risks in vulnerable watersheds to prevent increased surface erosion and mass wasting leading to aggradation of river channels.
- Improve or decommission roads to reduce adverse impacts during large storms to prevent surface erosion and fill slope failure and landslides. Construct stream crossings and bridges to withstand major storm and runoff events.
- Include standards to assess geologic hazards for management activities, including potential landslide hazards and risks, particularly as the population and infrastructure continue to increase in areas adjacent to the National Forest.
- Revegetate bare soil as soon as possible and suspend or eliminate recreation uses that are causing elevated sediment levels to streams and large areas of long term loss of soil productivity outside the designated use area.
- Increase riparian buffers and include channeled ephemeral streams in the riparian corridor.
- Consider nutrient replacement when planning vegetative management and/or look for alternative solutions (such as watershed liming or fertilization) in acid-sensitive watersheds.

- Identify soils highly sensitive to acid deposition and nutrient loss. Do not allow whole tree harvesting in those areas and consider possible soil fertilization treatments.
- Relocate, close or decommission roads causing significant resource damage.

Carbon Sequestration

National Forest System lands have opportunities for 1) biomass sequestration and storage of CO_2, and 2) geologic sequestration and storage of CO_2.

<u>**Biomass sequestration:**</u>

Trees and forests represent major biological "carbon sinks," places where carbon is sequestered. Carbon accrues in trees, soil, and wood products and the use of wood-based substitutes for fossil fuel-based products decreases the amount of greenhouse gas emissions.

Planting trees is often suggested as a way to "offset" the increased human contributions to atmospheric CO_2 that have led to global climate change, with some schemes actually tallying how many new trees it would take to offset a year of car emissions. But it's hard to make those calculations accurately because just how much carbon trees sequester—and more importantly, how that might change in response to heightened CO_2—is not precisely known. (http://www.srs.fs.usda.gov/compass/issue10/03carbon.htm)

Scientists working in the area do know one thing: It's not going to be as simple as "more trees, more carbon sequestered." And there are other, maybe more pressing questions: How will the forests we rely on change in response to climate conditions? Can forest management play a part in adapting forest ecosystems to climate change? (http://www.srs.fs.usda.gov/compass/issue10/03carbon.htm)

Sustainable forestry practices can increase the ability of forests to sequester atmospheric carbon while enhancing other ecosystem services, such as improved soil and water quality. Planting new trees and improving forest health through thinning and prescribed burning are some of the ways to increase forest carbon in the long run. The most defensible options for managing forests for their carbon storage are keeping forests as forests, reforesting areas where forests historically occurred, using forest biomass to offset fossil-fuel use (burning forest biomass generally means that fossil fuel will not be burned), and promoting long-lived forest products such as wood-framed buildings. Forests (particularly older forests) generally store carbon better than forest products, so harvesting old-growth forests for their forest products is not an effective carbon conservation strategy (Harmon et al. 1990). However, harvest and regeneration of young to middle-aged forests for long-lived forest products can help with carbon storage (Ryan 2008). On the GWNF, the age class distribution is heavily skewed to the mid- to late-successional age classes and we are harvesting less than ½ of 1% of our acres per year. So essentially we are managing for long rotation ages already.

<u>**Geologic Sequestration:**</u>

The Forest contains some lands with limestone bedrock. The weathering of limestone creates a carbon sink. The functioning of this carbon sink is influenced by the geologic characteristics of the limestone and by precipitation and runoff. Because the Forest's limestone areas will not be converted to urban-type development (i.e. paved over), the limestone area will function as a carbon sink.

In addition to this passive carbon sink of carbonate bedrock, the Congress and executive branch are considering the emerging technology of geologic sequestration and storage of CO_2 and its use on federal lands. This active use of a geologic sink can use a much wider range of geologic environment than carbonate bedrock.

In May 2009, the U.S. Department of Energy released a comprehensive study of geologic carbon sequestration and storage (CSS) on federal lands in "Storage of Captured Carbon Dioxide Beneath Federal Lands", (National Energy Technology Laboratory, 2009). This report characterizes and estimates the geologic storage potential as well as regulatory issues on all federal lands. The FS and BLM are the two agencies with the lion's share of opportunity for geologic CSS.

On June 3, 2009 the U.S. Department of Interior issued a report to Congress entitled *Framework for Geological Carbon Sequestration on Public Land*. In the News Release announcing the report, the DOI stated:

"President Obama's national energy plan calls for reducing greenhouse gas emissions by 80 percent by 2050," said Secretary Salazar. "Capturing carbon dioxide emissions in secure geologic formations prevents their release into the atmosphere, reducing the carbon intensity of our economy. These recommendations provide a structure for a national initiative to identify appropriate public land geological sequestration sites that will help us reach our clean energy goals."

At the current time, it is not possible to assess what role geologic CCS may play on federal land. However, in the context of developing a Forest Plan that must consider adaptive management over 10-15 years or longer, it is appropriate to be aware of Congressional and executive branch known interest in geologic sequestration and storage of carbon.

Management strategies for increasing carbon sequestration on the GWNF are:

- Improving stocking conditions on poorly stocked stands.
- Thinning.

Existing Stresses

An early detection and response strategy associated with nonnative invasive species will be critical to limit new introductions. Aggressive treatment of established invasive species, along with the control of insects and diseases, are likely to become more critical to maintaining desired conditions for healthy forests under a changing climate. Due to the fragmented land ownership patterns, success in reducing forest pests will sometimes require going beyond national forest boundaries, and continued work with partners will be needed. In addition, management practices (such as thinning and age class diversity) that sustain healthy forests and provide adequate nutrients, soil productivity, and hydrologic function promote resilience and reduce opportunities for disturbance and damage.

Management strategies for mitigating existing stresses are:

- Southern pine beetle infestations should be quickly addressed. Silvicultural options for decreasing the vulnerability of attack could include low intensity fire and lower basal areas.
- Aggressive treatment of highly invasive nonnative invasive plant and animal species.

Alternative Energy Demands

Using cleaner energy reduces greenhouse gases. Renewable energy development plays a significant role in the agency's implementation of the Energy Policy Act of 2005, Public Law 109-58 (Testimony by Sally Collins, Associate Chief Forest Service, before the Committee on Energy and Natural Resources, United States Senate, Renewable Energy on Federal Lands, July 11, 2006). The sources of renewable or alternative energy that can be provided on national forest system lands include: wind energy, solar energy, and natural gas leasing. Renewable energy such as wind and solar

Natural gas

Among fossil fuels, natural gas is a cleaner source of energy, producing less greenhouse gas than oil or coal. Natural gas is part of strategies for using cleaner energy. For example, natural gas can be part of wind or solar energy systems by supplying supply energy when wind or solar power is unable to meet continuous power demands.

The Forest Plan will address opportunities to explore for and supply natural gas as part of the Congressionally-mandated consideration of federal oil and gas leasing on National Forests System lands (Federal Onshore Oil and Gas Leasing Act of 1987).

Management strategies for the GWNF to provide alternative energy opportunities are:

- Revisit the oil and gas leasing availability analysis and decision.
- Consider the potential demand for alternative energy sources on the GWNF and provide management direction in the Forest Plan.

Sustainable Operations and Partnerships

The Forest will work with the state of Virginia to incorporate the greenhouse gas emissions from our management activities into a State inventory, just as we have done with the fine particulates inventory.

The Forest will continue striving to reduce its environmental footprint and decrease the greenhouse gases emitted through day-to-day operations, including the use of more fuel-efficient vehicles, reducing the number of miles driven and making facilities more energy-efficient.

The Forest will also continue working with partners, including other federal agencies, State and local governments, non-governmental organizations and other stakeholders to be more effective in efforts to adapt lands, ecosystems, and species to climate change. Examples are the Nature Conservancy in the Fire Learning Network and the Chesapeake Bay Partnership.

Monitoring and Future Research Directions

As noted in the previous section, many current management strategies can be used or adjusted to address changing climate conditions. As researchers develop more localized projections of anticipated climate changes and ecosystem responses are better understood, more specific management practices and strategies can be incorporated in the future.

Part of better understanding the interactions among the many climate change factors that could affect the George Washington National Forest will be monitoring how natural disturbances are affecting the forest. Climate change is a challenge to address in our annual monitoring program at the local forest level because there are multiple influences that are not well understood and many of the indicators are observable only at a very broad level over extended periods of time. However, forest disturbance has been identified as an indicator that can be observed (Dale et al. 2001). Although direct cause-effect relationships of individual disturbance events may not always be evident, it should be possible to see changes over time and determine whether they may be related to climate change factors. While current monitoring looks at disturbances such as insect and disease infestations, broadening these efforts to track damage from storm events and weather extremes could help predict threats to desired conditions and cope with changes.

In addition to including disturbances in the monitoring questions that are part of the monitoring program for the Forest Plan, the Southern Research Station (SRS) is a key partner in developing approaches for monitoring climate change and associated disturbances, and monitoring direction will be well coordinated with climate change scientists. Some initial ideas for monitoring and adapting to climate change-related disturbances include:

- Monitor changes in phenology (the timing of ecological events such as budburst and the arrival of migratory species),
- Consistently reporting disturbance events and tracking whether they are increasing in frequency,
- Evaluating impacts these disturbances and management responses have on advancing or deterring progress toward desired conditions in forest plans,
- Evaluating our organizational capacity to respond to disturbances and extreme climate-related events (droughts, fire, floods),
- Evaluating changes in condition caused by disturbances and extreme climate-related events (droughts, fire, floods),
- Evaluating the need to modify desired conditions and objectives in forest plans in light of the impacts of disturbances,
- Standardizing our monitoring questions and measures regionally to allow cumulative effect evaluations of climate change across the Southern Region
- Documenting species composition during the three and five year regeneration surveys
- Documenting noted changes in phenology events across the forest.

The SRS and other national and regional researchers are actively working on numerous projects to assess anticipated effects and appropriate actions in regard to climate change. Over the next few years, the SRS will be working on regional climate scenarios that start with the Global Circulation Models and then use regional climate models to scale down to a finer resolution that is useful to local forest managers. SRS scientists will also be continuing studies on increasing the resilience and carbon sequestration of gulf coast forests, particularly longleaf pine in Mississippi. Other future research needs include recommendations on how to mitigate hurricane impacts, expanded management options for coping with extended droughts and more extreme storms, appropriate carbon mitigation measures, and a better understanding of the likely ecological effects of anticipated disturbances.

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